Codes and Standards Enhancement Initiative
For PY2004: Title 20 Standards Development

Analysis of Standard Options For Under Cabinet Fluorescent Fixtures Attached to Office Furniture

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1 Introduction

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers under cabinet fluorescent fixtures attached to office furniture.

2 Product Description

The most common light used in office furniture is the under cabinet fluorescent task light (DOE 2). Three main components determine their efficiency: fixture design, lamps and ballasts. While the design of fixture optics is important in determining how much light is distributed to the workspace, due to the complexity in addressing fixture optics this proposal assesses only lamp and ballast efficacy.

Fluorescent lamps have been through many changes due to improvements in technology as well as regulation. The market has traditionally been dominated by the T12 lamp (only option until recently), which is 1-½ inches (12/8ths of an inch) in diameter. Fluorescent lamps come in a variety of lengths from 18 inches to 8 feet long. When electrical current flows from one end of the tube to the other it generates ultra-violet light. This UV light interacts with the phosphors that coat the inside to the tube and cause it to fluoresce. All other factors, such as lamp temperature, pressure, and current being equal, it is the mix of these phosphors that largely determines how efficacious a lamp is. The "new" T8 lamps makes use of phosphors that fluoresce more efficiently enabling a reduction in diameter of the lamp to 1 inch (8/8ths of an inch) without any loss in the amount of light (lumens) produced. In addition to saving energy T8 lamps have a number of advantages over T12 lamps:

- Smaller diameter – this is ideal for under cabinet lighting where space is at a premium.
- Higher quality light – new phosphors produce a light that has a higher CRI (Color Rendering Index)
- Long lamp life – higher-end T8 lamps are rated at between 24,000 and 30,000 hours compared to 15,000 to 20,000 hours for T12 lamps
- Less lumen depreciation – depreciates about 10 percent over the life of the lamp compared to 15-25 percent for the most commonly installed T12s.

The ballast is an electrical control device that provides the correct voltage and current in order to enable the fluorescent lamp to function correctly. The amount of electricity the ballast consumes depends on how the ballast regulates the voltage and current. The BEF (Ballast Efficacy Factor) is an industry standard efficiency metric that was created to measure the ballasts effectiveness in converting input power (watts) to lumen output, used to drive the lamps. Currently there are two types of ballast: electromagnetic (magnetic) and electronic.

Until recently magnetic ballasts were the only option. Magnetic ballasts consist of a core of steel laminations and copper coils that transform electricity supplied to a voltage and current form appropriate for starting and regulating fluorescent lamps. A new generation of "energy saver" magnetic ballasts was developed in the 1970's but did not become dominant in the market until the National Appliance Energy Conservation Act of 1988 mandated their use. These ballasts were able to increase the power factor and decrease ballast energy losses slightly.

The next generation, electronic ballasts, used the new electronic technology to dramatically improve the efficiency of ballasts. The electronic ballast converts the standard operating frequency of electricity (60 Hz or cycles per second) to frequencies from 20,000 and 60,000 Hz. These higher frequencies enable fluorescent lamps to produce about 10 percent more light than magnetic ballast with the same amount of energy used. Electronic ballasts have the following advantages over magnetic ballasts:

- Reduction in power consumption – from 15 to 30 percent energy savings in fluorescent bulbs in lengths from 24 to 48 inches.
- Reduced shipping cost – smaller and lighter ballasts reduce shipping and storage costs. They are also easier to work with and fit into more applications
- Increased flexibility – enable lamps driven by the same ballast to continue to operate independently of the other lamps (only true for instant start ballasts, which hold 90 percent of the market). Magnetic ballasts operate in a way such that when one lamp burns out the other lamps driven by that ballast would no longer receive the correct current to operate.
- Provide higher quality light – due to the increase in frequency of electronic ballasts the "stroboscopic effect" that can sometimes be seen with magnetic ballasts is eliminated
- Quieter operation – All electronic ballasts are rated Class A or better, eliminating the "humming" noise common to magnetic ballasts
- Enable Dimming – enable dimming capability at a more economical price. This is due to new technology that incorporates the dimming technology into the ballast.

3 Market Status

3.1 Market Penetration

The 2003 Technical Support Document for ballasts (DOE 2002, B) estimates that there were 1,552 million fluorescent lamps installed in commercial, industrial and non-residential applications in the U.S. in 2001. T12 lamps are the most common lamp and account for between 65 to 70 percent of the installed base (DOE 2002, B). T8s make up the remaining 30 to 35 percent and the 2002 U.S. Lighting Market Characterization (DOE 2002, A) estimates that 63 percent of all installed T8 are electronically ballasted.

Approximately five percent of all commercial fluorescents lamps that had been installed as of 2000 were used in under cabinet lighting (Census 2000), which suggests that there are about 78 million under cabinet fluorescent lamps in service in the U.S. California accounts for about nine percent of U.S. Commercial building floor area (CEC 2003, EIA

2002). Assuming the same ratio, we estimate that seven million under cabinet fluorescent lamps are in service in California.

Electronically ballasted T12s have a negligible market share and are therefore ignored in this evaluation. Assuming the national ratios apply to California the current stock is distributed as follows: T12 magnetic – 4,550,000 lamps, T8 magnetic – 735,000 lamps, T8 electronic – 1,715,000 lamps. This means that 5.3 million lamps could be affected by a standard requiring the use of electronic ballasts in fixtures for under cabinet installations in office furniture.

Under cabinet fixtures vary in number of lamps per fixture and lamp length. Based on conversations with equipment and furniture manufacturers, it appears reasonable to assume that slightly more than half of under cabinet linear fluorescent fixtures are designed for two lamps with the remainder having a single lamp. Furthermore, because the percentage savings per lamp varies only slightly (if at all) with respect to length (See Table 2) lamp length was not a crucial factor.

3.2 Sales Volume

The office furniture market place is dominated by a few major companies. Steelcase and Herman Miller each have approximately 30 percent of the market with Haworth Inc, Knoll Inc and Hon Industries making up another 20 percent (Steelcase, 2003). The office furniture market experienced a boom that peaked in 2000 with sales of over 13 billion dollars. The market has since receded to approximately 8.5 billion dollars and is expected to stay between 8 and 9 billion dollars per year in sales through 2004 (BIFMA 2003).

The 2002 Census reports that sales of under cabinet fluorescent fixtures were 3.1 million in 2000 and 2.7 million in 2001. California accounts for about nine percent of the U.S. commercial building floor area (CEC 2003, EIA 2002). If California also accounts for nine percent of all under cabinet fluorescent lamp sales, California sales totaled an estimated 280,000 fixtures in 2000 and 240,000 in 2001. According to two major ballast manufactures overall ballast sales for both T12 and T8s together are about equal between electronic and magnetic and have been so since 2000.

3.3 Market Penetration of High Efficiency Options

New office furniture sales are dominated almost exclusively by T8 fixtures with some major furniture manufacturers not even offering T12 under cabinet fixtures as an option. Although about 30 percent of all recent T8 fixture sales are magnetically ballasted the market is moving towards exclusive use of electronic ballasts, except for special applications for which electronic ballasts are unacceptable. According to two major furniture manufacturers, T8 magnetic ballast sales had been decreasing until about three years ago when they evened out at between 12 to 25 percent of the under cabinet market. This is likely due to the continued sales of entry-level products with magnetic ballasts.

4 Savings Potential

4.1 Baseline Energy Use

The installed base of all fluorescent lamps in the U.S. consumes an estimated 220 TWh per year (DOE, 2002, A). Nationally, five percent of the installed base is under cabinet (Census 2002). Nine percent of commercial office space is in California (CEC 2003, EIA 2002). Incorporating those numbers and the wattage per lamp based on lamp lengths used in under cabinet fluorescent market, we estimate that under cabinet fluorescent lighting in California consumes an estimated 500 GWh per year. In the next paragraph we estimate what the energy use baseline is for current and future sales against which to compare a proposed standard.

Baseline energy consumption of fluorescent fixtures varies with the specific lamp/ballast combination. Table 1 summarizes energy use for typical lamp/ballast combinations. The input system wattage is based on published operating wattage data from Advance Transformer, Osram/Sylvania and Universal Lighting Technologies (see Appendix A). PG&E's 2001 Energy Efficiency Program Attachment K estimates that the operational hours for lights in an office application to be 4000 hours a year. Task lighting is used less than overhead lighting so we used a more conservative estimate of 2000 hours per year. Under cabinet fixtures and lamps come in lengths of 24, 30, 36, 42 and 48 inches. Data for ballasts designed for 2, 3, 4, and 8-foot lamps were readily available, so consumption and savings data was developed on the basis of the 2, 3, and 4-foot lamp data. As can be seen, the annual energy use ranges from 86 down to 56 kWh per fixture per year.

Table 1: Typical Energy Use Estimates for a 4' one lamp/ballast combination

	T12 Magnetic Ballast	T12 Electronic Ballast	T8 Magnetic Ballast	T8 Electronic Ballast	T8 Electronic Ballast (high efficacy)
Typical Fluorescent Lamp (Rated)	34 watts	34 watts	32 watts	32 watts	32 watts
Input System Wattage	43 watts	34 watts	35 watts	31 watts	28 watts
Annual Operating Hours	2000	2000	2000	2000	2000
Annual Energy Use	86 kWh	68 kWh	70 kWh	62 kWh	56 kWh

See Appendix A for more detailed wattage and efficiency information

In defining the baseline energy use we eliminated the T12 magnetic ballasts because they will be regulated by the federal standard. T12 electronic ballasts were eliminated because they have insignificant market share. Our baseline energy use is the T8 magnetic ballast, which demands 35 watts and uses 70kWh per fixture, annually. As suggested by the last two columns above, there is a range of performance between different T-8 electronic ballasts.

4.2 Proposed Test Method

The appropriate test procedure for testing fluorescent ballast efficiency is 10 CFR Section 430.23(q) (2004), which references ‘‘American National Standard for Fluorescent Lamp Ballasts—Method of Measurement 1984’’[ANSI Standard C82.2–1984].

4.3 Efficiency Measures

The efficacy of fluorescent lighting can be increased by using a using an electronic ballast in place of a magnetic ballast. This change will reduce the fixture wattage between 4 and 10 watts depending on the length and number of lamps that the ballast was designed to operate. In addition, the use of T8 lamps can reduce the system wattage by 5 to 10 watts, as well.

While system wattage is a good predictor of energy use it does not provide any information about overall lighting efficiency or efficacy. There are different metrics for assessing the performance of just the ballast or the lamp/ballast combination. The BEF discussed earlier measures the ballast efficacy with respect to a reference lamp and ballast. Combined lamp/ballast lighting efficacy is measured in lumens/watt.

4.4 Standards Options

When establishing efficiency standards for fluorescent fixtures there are three main approaches to consider: efficacy standards for ballasts only, efficacy standards for lamp/ballast combinations, and prescriptive technology standards for ballasts only.

<u>Standard for Ballasts</u>

A standard for ballasts sets a minimum acceptable ballast efficacy factor (BEF). The BEF is higher for electronic ballasts than it is for magnetic ballasts designed for the same length lamp. There is not a technical reason that T12 electronic ballast should have a lower BEF than a T8 electronic ballast but in general they are not as high. This is likely due to lower sales volume and less investment in improving a technology that appears to have already been surpassed by electronic T8s. In addition, the BEF is drastically different between ballasts designed for different length lamps; therefore distinct standards for each length range should be established.

A general BEF standard could be established, but this may overlap with the federal efficiency regulation regarding T12 electronic ballasts. For this reason this standards approach should be limited to T8 ballasts, which are not federally regulated.

<u>Efficacy Standard for Lamp/Ballast Combinations</u>

An efficacy standard for lamp/ballast combinations sets a minimum ratio of lumens/watt used in under cabinet fixtures. This is similar to the standard for ballasts discussed above but factors in the efficacy of lamp. Again, in order to avoid conflict with the federal standard this approach is focused only on T8s. This standard would have a similar effect on ballasts as with the previous approach using BEF, and it could be designed to encourage the use of more efficacious lamps (mainly 800 series lamp over the older 700 series). This approach would be more difficult to implement and enforce because it is common to buy the lamps and ballasts separately.

Prescriptive Technology Standards for Ballasts

A prescriptive standard for ballasts would simply bar the sale of magnetic T8 ballasts in under cabinet fixtures. This approach would eliminate all magnetic T8 ballasts, but would not have any effect on lower efficacy T8 electronic ballasts or T8 lamps. By far the least complicated, this approach would fail to address low efficacy electronic ballasted fixtures.

We believe the first approach, Efficacy Standard for Ballasts, strikes the best compromise between simplicity and savings impacts. Thus, this approach is the basis for standards options considered and the energy and economic analysis in the following sections. Within this approach there are a number of possible levels at which the standard could be set. The following is an analysis of the three levels and the affected products for each level.

- Low - Slightly above the BEF for all magnetic ballasts

  This would eliminate all T8 magnetic ballasts from the under cabinet market.

- Medium - Slightly below the BEF of average electronic ballasts

  In addition to the low standard impacts, this would eliminate all non-efficacious (low BEF) electronic ballasts.

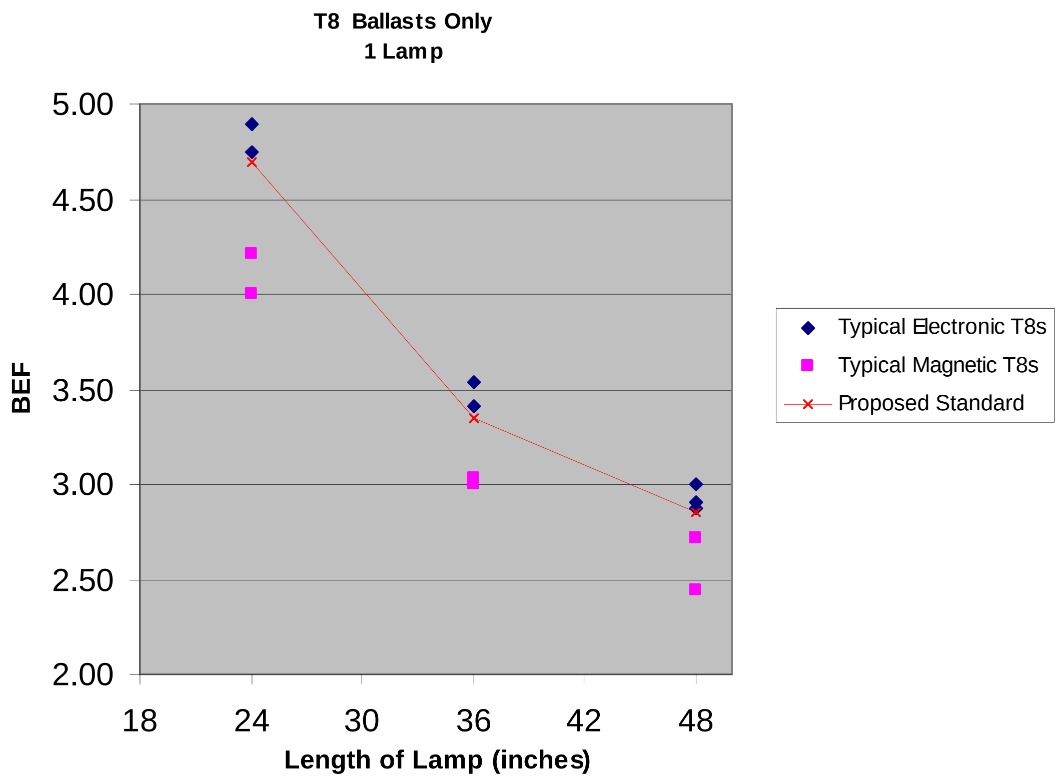
- High - Between the BEFs for average electronic ballast and high efficacy electronic ballasts

  In addition to the medium standard this would eliminate the use of the average (most common) electronic ballast that manufacturers produce today.

In examining the three levels it became apparent that the high standard would have large impacts on the price of the fixture due to the low volume of high BEF ballasts currently being produced. We do not feel that it is a feasible standard at this time. The low standard will impact a smaller portion of the market and has no significant advantages over the medium standard. For these reasons the savings analyses in the following sections will be focused on the medium standard.

The medium standard is illustrated in Figure 1 below. The data points are taken from Appendix A, each lamp length has two representative data points, (one from Advance and one from Sylvania) for each of the two ballast types (Electronic and Magnetic).

Figure 1: Graphical representation of the recommended standard for one lamp T8 BEF standard.



4.5 Energy Savings

Table 2 provides estimates of energy savings per fixture by using a typical T8 electronic ballast in place of a typical T8 magnetic ballast. In each case below the energy savings were calculated from performance data shown in Appendix A for like fixtures, but using an electronic ballast rather than a magnetic ballast.

Table 2: Typical Energy Savings per fixture

	1 lamp			2 Lamp		
	2'	3'	4'	2'	3'	4'
Energy Savings (watts)	4	4	4	13	12	11
Annual Operation Hours	2000	2000	2000	2000	2000	2000
Energy Savings per year (kWh)	8	8	8	26	24	22

Note: Savings are in actual not coincident demand

In order to calculate the statewide savings when stock turns over we started with the seven million under cabinet fluorescent lamps currently installed (see Section 3.1). As noted in Section 3.1, 5,285,000 of those will be replaced by T8s lamps. Of the stock that will turn over, an estimated 20 percent (average of values in Section 3.1) or 1,057,000 lamps would be expected to be installed with magnetic ballasts in the absence of a standard. This is the quantity, therefore, that would be affected by the proposed standard.

To calculate the annual energy savings the number of fixtures, 705,000 (1,057,000 lamps divided by 1.5 lamps per average fixture) are multiplied by the per fixture annual energy savings (16 kWh), which is the straight average of the energy savings per year from Table 2, above. This calculation yields a statewide annual energy savings of 11 GWh.

To calculate the Coincident MW, 1,057,000 is multiplied by the 5W demand reduction per lamp yielding 5.3 MW connected load savings. The 5W reduction was calculated by dividing demand savings per fixture by the number of lamps for all lengths and averaging (Table 2). The statewide reduction in connected load of 5.3 MW is then multiplied by an estimated coincident factor of 0.4 (see note b in Table 3) to arrive at the coincident peak demand savings of 2.2 MW. Thus, substituting the electronic ballast will reduce the energy use by an average of 17.5 percent per fixture over all lamp lengths while keeping the light levels roughly the same.[1]

Table 3 is a summary of the calculations above. It shows both the first year savings and the total technical potential annual savings.

Table 3: Estimated Statewide Energy Savings for Proposed Standard

Per Fixture Annual Savings			Statewide savings per year when entire stock turns over		Statewide savings for first year's sales	
kWh	Watts	Percent	GWh	Coincident MW	GWh	Coincident MW
16	8	17.5%	11	2.2	1	0.2

Note: a) Calculations based on equal distribution of lamp lengths. b) Coincident demand for office environments is .81 (PG&G, 2000) but not as big a proportion of task lights are presumed to be on during peak hours or for as long so we used a conservative coincident factor of .4, which is 50% lower in proportion to the assumed lower annual hours of operation.

5 Economic Analysis

5.1 Incremental Cost

Discussions with two major ballast manufacturers indicate that across all cost structures (manufacturer, wholesale and retail) that electronic ballast fairly consistently cost about 20 percent to 25 percent more than magnetic ballasts. The wholesale cost for electronic ballasts have come down from $20 ten years ago to about $14 five years ago and are down to about $10 to $11 today. This compares to between $7 and $8 for magnetic ballasts. In 2005 the federal standard forbidding T12 magnetic ballast sales for new construction will go into effect. This standard is expected increase the volume of T8 electronic ballasts, likely driving the price down further. The volume of magnetic ballasts may then decrease, causing their price to go up. There is not a significant difference in price between one and two lamp ballasts. The installation cost associated

[1] This is an un-weighted average and is provided as a simplistic illustration of savings potential.

with electronic and magnetic ballasts are the same. Thus, we assume a $3 incremental cost at wholesale, which we presume leads to an approximate $5 incremental cost at the retail level.

5.2 Design Life

There is not a significant difference in the ballast life of typical electronic and magnetic ballasts. They are rated at about 60,000 hours. T8 lamps have a rated lamp life of between 20,000 to 30,000 hours compared to T12 lamps that have a rated lamp life of between 15,000 and 20,000 hours. The type of ballast (i.e. rapid start, instant start, programmed start) and how often it is started will affect the actual lamp life. For lack of better data on the life cycle for office furniture and their implications for the life cycle of attached fixtures, we assume a 15-year life cycle on each fixture. The life of under cabinet lighting fixtures attached to modular furniture is probably more affected by the building remodeling cycle than the actual equipment life.

5.3 Life Cycle Cost

Table 4 summarizes the life cycle cost savings from switching from magnetic to electronic ballasts. As noted, the lamp and ballasts' rated life for magnetic and electronic ballasts are essentially the same.

Table 4: Analysis of Customer Net Benefits

Option	Energy Savings (kWh/year)	Incremental Cost	Present value of savings (15 years)*	Customer Net Present Value**
1 Lamp T8 electronic ballast	8	$ 5.00	$ 7.86	$ 2.86
2 Lamp T8 electronic ballast	24	$ 5.00	$ 23.57	$ 18.57

*Present value of energy savings calculated using a Life Cycle Cost of $0.982/kWh (CEC 2003).
**Positive value indicates a reduced total cost of ownership over the life of the appliance

6 Acceptance Issues

6.1 Infrastructure Issues

No major infrastructure issues are anticipated from the proposed standard. Electronic ballasts appear to have the majority of the market share in the under cabinet office furniture market. All major ballast manufacturers are already producing large quantities of T8 electronic ballasts. Many of the under cabinet lighting fixtures that are sold as accessories for office furniture already include T8 lamps with electronic ballasts. Generally, if a T8 magnetic fixture option is offered at all, it is as the "base" model with higher quality fixture options being offered that include electronic ballasts. Thus, the full market delivery channel is already geared up for electronic T8 ballast sales.

6.2 Existing Standards

Federal regulations (EPACT) adopted by California, which take effective in 2005, require electronic ballasts for T12s in commercial applications, but there are currently no standards set for T8 ballasts.

7 Recommendations

We recommend a ballast efficacy standard designed to eliminate magnetic and lower BEF electronic T8 ballasts from under cabinet fixtures. This standard would apply to all under cabinet fixtures intended to be attached to office furniture. The table below sets out the proposed minimum BEF for T8 ballasts.

Specifically, we recommend that the following be added to Section 1605.3 of the current CEC Appliance Efficiency Regulations:

(j) Fluorescent Lamp Ballasts

Energy Efficiency Standard for T8 ballasts. *The ballast efficacy factor for all T8 ballasts in under cabinet fixtures designed to be attached to office furniture sold in the State on or after January 1, 2006 shall meet or exceed the applicable values shown in Table J, except for T8 ballast designed for dimming.*

Table J

Standards for Ballasts

Lamp Length (inches)	*Ballast Efficacy Factor (BEF) for 1 Lamp*	*Minimum Ballast Efficacy Factor (BEF) for 2 Lamps*
=29	*4.70*	*2.80*
30 and 35	*3.95*	*2.30*
36 and 41	*3.40*	*1.90*
42 and 47	*3.05*	*1.65*
=48	*2.80*	*1.45*

8 References

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Steelcase Inc. 2003. Personal communication with representative. November.

Appendix A

Ballast Type	Lamp Type	Manufacturer	Lamp Watts	Fixture Watts	Ballast Factor	Ballast Efficacy Factor	Lamp Lumens	Lumens /Watt	800 series Lumens	800 series Lumens /Watt
1 Lamp										
	2'									
Magnetic	F17T8	Advance	17	24	1.01	4.21	1325	56	1400	59
Magnetic	F17T8	Universal	17	24	0.96	4.00	1325	53	1400	56
Electronic	F17T8	Advance	17	20	0.95	4.75	1325	63	1400	67
Electronic	F17T8	Universal	17	19	0.93	4.89	1325	65	1400	69
	3'									
Magnetic	F25T8	Advance	25	31	0.94	3.03	2050	62	2250	68
Magnetic	F25T8	Universal	25	32	0.96	3.00	2050	62	2250	68
Electronic	F25T8	Advance	25	27	0.92	3.41	2050	70	2250	77
Electronic	F25T8	Universal	25	26	0.92	3.54	2050	73	2250	80
	4'									
Magnetic	F32T8	Advance	32	35	0.95	2.71	2800	76	2950	80
Magnetic	F32T8	Universal	32	36	0.88	2.44	2800	68	2950	72
Electronic	F32T8	Advance	32	32	0.92	2.88	2800	81	2950	85
Electronic	F32T8	Universal	32	33	0.96	2.91	2800	81	2950	86
Electronic	F32T8	Osram/Sylvania	32	30	0.9	3.00	2800	84	2950	89
2 Lamp										
	2'									
Magnetic	F17T8	Advance	17	47	0.96	2.04	2650	54	2800	57
Magnetic	F17T8	Universal	17	44	0.96	2.18	2650	58	2800	61
Electronic	F17T8	Advance	17	34	0.98	2.88	2650	76	2800	81
Electronic	F17T8	Universal	17	30	0.88	2.93	2650	78	2800	82
	3'									
Magnetic	F25T8	Advance	25	62	0.97	1.56	4100	64	4500	70
Magnetic	F25T8	Universal	25	58	0.93	1.60	4100	66	4500	72
Electronic	F25T8	Advance	25	47	0.9	1.91	4100	79	4500	86
Electronic	F25T8	Universal	25	48	0.93	1.94	4100	79	4500	87
	4'									
Magnetic	F32T8	Advance	32	71	0.99	1.39	5600	78	5900	82
Magnetic	F32T8	Universal	32	69	0.88	1.28	5600	71	5900	75
Electronic	F32T8	Advance	32	59	0.87	1.47	5600	83	5900	87
Electronic	F32T8	Universal	32	58	0.88	1.52	5600	85	5900	90
Electronic	F32T8	Osram/Sylvania	32	59	0.9	1.53	5600	85	5900	90